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THE WIPE SOLVENT PROGRAM
Delivery Order 0005: Fluids, Lubricants, and Related Materials

Marcie B. Roberts (UDRI)
Lois J. Gschwender (AFRL/MLBT)
Carl E. Snyder, Jr. (AFRL/MLBT)

University of Dayton Research Institute (UDRI)
300 College Park
Dayton, OH 45469-0170

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MATERIALS AND MANUFACTURING DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7750

NOTICE

This technical report has been reviewed and is approved for publication.

LOIS J. GSCHWENDER, Program Manager
Nonstructural Materials Branch
Nonmetallic Materials Division

JEFFREY S. ZABINSKI, Chief
Nonstructural Materials Branch
Nonmetallic Materials Division

ROBERT M. SUSNIK, Deputy Chief
Nonmetallic Materials Division
Materials and Manufacturing Directorate

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Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
This report contains color.

14. ABSTRACT ***(Maximum 200 Words)***
Freon 113 TF® solvent, 1,1,2-trichloroethane (Freon 113®) was widely used to clean equipment. With the banning of many halogenated solvents due to ozone depleting tendencies, users desperately sought substitute environmentally friendly solvents. In many cases, the substitutes did not work as well and had other issues that made them less than ideal. Often, it was difficult to assess various solvents based on the manufacturers' claims. In this work, which was directed to the development of replacement solvents for wipe and liquid cleaning of liquid and gaseous oxygen systems, the authors evaluated seven solvents, plus Freon 113® as a baseline, that were advocated as Freon 113® replacements. First, the cleaning ability was evaluated on oxygen system components. These solvents were also tested for compatibility with oxygen systems using the Liquid Oxygen Mechanical Impact Test and by determining the Autogenous Ignition Temperature in pure oxygen. In addition, elastomers seals Nitrile, Silicone, Viton A, Buna N, polytetrafluoroethylene, and Kel F were evaluated with the solvents. Elastomer damage on prolonged contact with most solvents was similar to Freon 113®. No single solvent performed as well as nor as universally as did Freon 113®, but some were close.

15. SUBJECT TERMS
3M tape 250 residue, Amberlube®, Autogenous Ignition Temperature, Buna N, Freon 113®, Kel F, Krytox 240AC® grease, Krytox 240AC®, Liquid Oxygen Mechanical Impact Test, MIL-PRF-7808, MIL-PRF-83282, Nitrile, polytetrafluoroethylene, Silicone, Viton A

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Purpose of Investigation

This wipe solvent program was initiated to find a replacement for Freon 113® for cleaning liquid and gaseous oxygen systems on board aircraft and ground servicing equipment. Freon 113® has been widely used for wipe cleaning because of its excellent cleaning abilities with a wide variety of soils and compatibility with oxygen systems. Now that production has been banned, an adequate substitute must be found. In the beginning of this project research was done to determine what requirements, performance characteristics and cost a new solvent should meet. To initiate this program, a kick-off meeting was held to which Air Force users, Air Force systems and laboratory personnel, and potential solvent suppliers were invited. [1]Performance requirements were determined through discussions with technicians that use Freon 113® and will be using the replacements identified through this study. Studies were conducted based on the important solvent properties identified. The results from several studies from different organizations are included in this report. Studies were conducted at the Air Force Research Laboratory unless otherwise indicated. The first two properties are concerned with the compatibility of the candidate solvents with liquid and gaseous oxygen, LOX and GOX respectively, which is critical to the safety of working with the solvents.

- Liquid Oxygen (LOX) Mechanical Impact
- Autogenous Ignition Temperature (AIT)
- System Materials Compatibility
- Immersion Cleaning Ability
- Wipe Cleaning Ability

Along with the properties tested in these studies the candidate solvents needed to be environmentally friendly and non-toxic in levels at user exposure levels.

Candidate Solvents

Initial testing was conducted at White Sands Testing Facility. A large number of solvents were included in this testing but the primary candidates include:

- HFE 71IPA® — Hydrofluoroether
- Ikon Solvent P — Perfluorinated Material
- Vertrel X-P10® — Hydrofluorocarbon/IPA
- Vertrel XF® — Hydrofluorocarbon
- Freon 113® — Trichlorotrifluoroethane
- AK 225G® — Hydrochlorofluorocarbon
- HFE 7200® — Hydrofluoroether
- HFE 7100® — Hydrofluoroether

Liquid Oxygen (LOX) Mechanical Impact Procedure

[2]LOX mechanical impact tests were performed at NASA White Sands Test Facility according to ASTM G86. Sample weight, thickness, and diameter could not be measured due to the evaporation rate of candidate solvents at room temperature. Approximately 0.3 mL solvent was used in each test. The test cup was approximately 1.783 cm in diameter. A test medium of 100 percent Liquid Oxygen was used at a temperature of –183^{0}C and a pressure of 85.5 kPa.

Twenty impacts were run initially. If there was one reaction the test was extended to 60 impacts at an energy of 72 ft-lbf. White Sands Test Facility commonly recommended energy levels are 72, 65, 60, 55, 50, 45, 40, 35, 30, 25, 20, 15, and 10 ft-lbf.

LOX Mechanical Impact Results and Data

LOX Mechanical Impact Results		
Solvent	**Result**	**Results**
Freon 113®	Pass	-
AK 225G®	Pass	-
HFE 7100®	Pass	-
HFE 7200®	Pass	-
Vertrel XF®	Pass	-
HFE 71IPA®	Fail	7 reactions in 60 72ft-lb impacts
Ikon P	Fail	0 reactions in 20 65ft-lb impacts, 2 reactions in 17 72ft-lb impacts
Vertrel X-P10®	Fail	5 reactions in 60 72ft-lb impacts

LOX Mechanical Impact Performance Standards

[2]To pass the test, the solvent must have no reaction in 20 impacts at any energy level or no more than one reaction in 60 impacts at an energy of 72 ft-lbf. The Ikon P, although it failed this test, was still included in the program for a number of reasons. First, although it did not pass the 72 ft-lbf energy level tests, it did pass the next level down, i.e., the 65 ft-lbf energy tests. Second, the energies involved in the ignitions were quite low compared to typical ignitions, so it was deemed that there was an acceptable risk for its use with LOX/GOX system maintenance. Third, its overall performance as a direct replacement solvent for Freon 113®, e.g., cleaning ability, compatibility with elastomers, boiling point, etc. made it very attractive to keep in the program.

Autogenous Ignition Temperature (AIT) Procedure

[2]The ASTM G 72 procedure was used for the AIT testing. Solvents were tested in 100% oxygen three times at a pressure of 0.0345 MPa (50 psia) and 5 times at a pressure of 13.8 MPa (2000 psia). The average sample weight was 0.22 ± 0.01 g and the heating rate was 5±1°C. The maximum vessel temperature was 450°C (842°F).

AIT Results and Data

AIT Results		
Solvent	AIT	Category
Freon 113®	@ 50 psia, no ignition @ 2000 psia, no ignition	C
AK 225G®	@ 50 psia, no ignition @ 2000 psia, no ignition	C
HFE 7100®	@ 50 psia, no ignition @ 2000 psia, no ignition	C
HFE 7200®	@ 50 psia, no ignition @ 2000 psia, 503 °F	C
Vertrel XF®	@ 50 psia, no ignition @ 2000 psia, 467 °F	C
HFE 71IPA®	@ 2000 psia, 538°F	C
Ikon Solvent P	@ 2000 psia, 345°F	B
Ikon Solvent P (Retest)	@ 2000 psia, 355°F	B
Vertrel X-P10®	@ 2000 psia, 519°F	C

AIT Performance Standards

[2]The following standards were determined through discussion between WSTF and Wright Patterson Air Force Base.

Category A	AIT < 250°F	Not recommended for oxygen system use
Category B	250°F < AIT < 400°F	Caution when used in oxygen systems
Category C	AIT > 400°F	Recommended for oxygen system use

Seal Compatibility Procedure

The equipment used for the compatibility study was: 4 oz wide mouthed jars with Teflon® lined caps, wire stands, balance, tweezers, and a Shore A Durometer. Three of each type of o-ring were weighed in water and in air to determine their volume. The rubber o-rings were also measured for hardness. Duplicate tests were conducted. The three o-rings were hung on a wire stand and placed in a wide mouth jar (see figure 1). Enough solvent was added to completely cover the o-rings. This resulted in approximately 50 mL of solvent being used per trial. One o-ring was removed from solvent after 30, 60, and 90 days. The seal weight was measured in air and in water immediately after being removed to determine the shrinkage or swell experienced by each seal. The hardness was also measured for the rubber o-rings. Upon removal from the solvent the weight of the rubber o-rings was not stable, it was decreasing due to solvent evaporation. After the weight stabilized the weight in air and water and the hardnesses were again measured. The averaged data is contained in tables 1 – 8. Graphs of the swelling data are in Appendix 1. Graphs of the hardness data are in Appendix 2. The hardness was only

measured for the rubber seals. The hardness of plastic seals did not change appreciably during this test as denoted by N/A (not applicable) in the tables.

Figure 1- Compatibility Study Apparatus

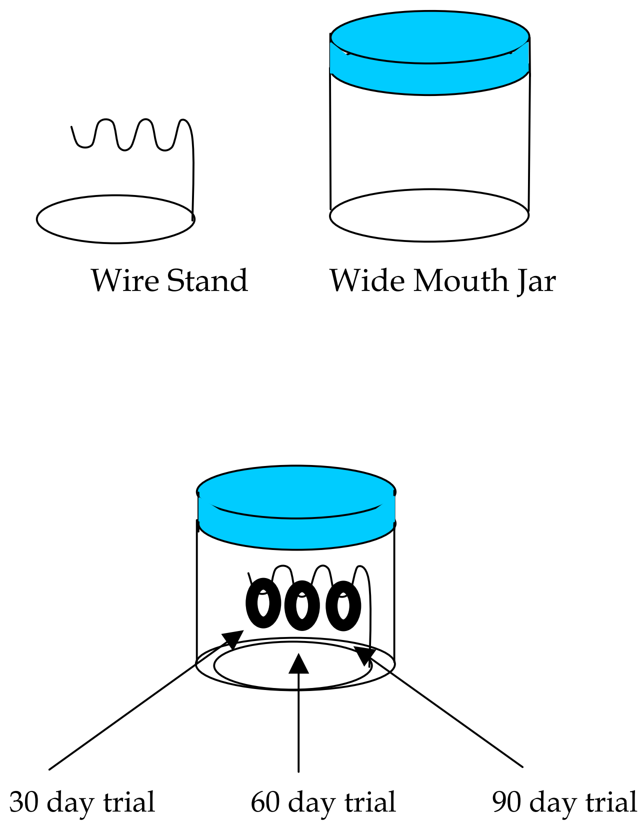


Table 1 - Freon 113® Compatibility					
		Post		After weight Stabilized	
O-Ring	Days	% Swell	% Hardness Change	% Swell	% Hardness Change
Buna N®	30	1.29%	0.94%	-4.49%	16.04%
Buna N®	60	0.04%	0.87%	-6.87%	13.88%
Buna N®	90	0.00%	0.69%	-7.61%	15.57%
KEL-F®	30	5.78%	N/A	N/A	N/A
KEL-F®	60	17.83%	N/A	N/A	N/A
KEL-F®	90	18.77%	N/A	N/A	N/A
Neoprene®	30	4.14%	-3.51%	-6.97%	15.86%
Neoprene®	60	3.15%	-3.19%	-5.19%	9.64%
Neoprene®	90	3.21%	-1.63%	-6.66%	10.61%
Silicone	30	137.67%	-11.41%	60.44%	-12.10%
Silicone	60	132.43%	-4.53%	-1.53%	-2.51%
Silicone	90	25.99%	-14.34%	-1.89%	-2.71%
TFE	30	5.92%	N/A	N/A	N/A
TFE	60	6.52%	N/A	N/A	N/A
TFE	90	6.94%	N/A	N/A	N/A
VITON-A®	30	21.01%	-10.08%	14.21%	-0.83%
VITON-A®	60	19.00%	-5.23%	11.25%	3.49%
VITON-A®	90	21.12%	0.97%	10.95%	3.68%

Table 2 - AK 225G® Compatibility					
		Post		After weight Stabilized	
O-Ring	Days	% Swell	% Hardness Change	% Swell	% Hardness Change
Buna N®	30	93.68%	-14.34%	25.18%	16.04%
Buna N®	60	96.90%	-15.72%	35.66%	15.57%
Buna N®	90	94.48%	-10.63%	35.25%	13.12%
KEL-F®	30	6.66%	N/A	N/A	N/A
KEL-F®	60	13.93%	N/A	N/A	N/A
KEL-F®	90	14.42%	N/A	N/A	N/A
Neoprene®	30	87.52%	-18.03%	43.51%	-33.32%
Neoprene®	60	91.91%	-17.96%	-8.42%	11.00%
Neoprene®	90	92.40%	-19.13%	-7.69%	9.25%
Silicone	30	109.69%	-13.77%	52.54%	-11.61%
Silicone	60	105.32%	-12.62%	10.35%	-0.08%
Silicone	90	109.12%	-12.22%	-2.15%	-0.49%
TFE	30	6.34%	N/A	N/A	N/A
TFE	60	6.50%	N/A	N/A	N/A
TFE	90	6.90%	N/A	N/A	N/A
VITON-A®	30	73.65%	-8.14%	8.17%	3.88%
VITON-A®	60	74.46%	-12.21%	23.73%	2.71%
VITON-A®	90	73.16%	-9.69%	34.40%	-0.58%

Table 3 - HFE 7100® Compatibility					
		Post		After weight Stabilized	
O-Ring	Days	% Swell	% Hardness Change	% Swell	% Hardness Change
Buna N®	30	-4.56%	5.28%	-4.51%	6.23%
Buna N®	60	-5.80%	6.52%	-6.56%	8.41%
Buna N®	90	-6.20%	5.20%	-8.22%	9.54%
KEL-F®	30	-0.75%	N/A	N/A	N/A
KEL-F®	60	11.38%	N/A	N/A	N/A
KEL-F®	90	-0.41%	N/A	N/A	N/A
Neoprene®	30	-3.94%	3.23%	-4.00%	5.75%
Neoprene®	60	-5.14%	9.25%	-4.96%	10.23%
Neoprene®	90	-5.54%	10.42%	-5.63%	10.81%
Silicone	30	13.45%	-5.74%	2.16%	1.13%
Silicone	60	13.07%	-8.98%	-1.24%	2.55%
Silicone	90	13.93%	-6.55%	-1.68%	-0.08%
TFE	30	4.81%	N/A	N/A	N/A
TFE	60	6.64%	N/A	N/A	N/A
TFE	90	7.34%	N/A	N/A	N/A
VITON-A®	30	30.43%	-9.69%	15.31%	1.74%
VITON-A®	60	30.61%	-6.98%	16.27%	2.91%
VITON-A®	90	30.38%	-5.81%	13.83%	0.78%

Table 4 - HFE 71IPA® Compatibility					
		Post		After weight Stabilized	
O-Ring	Days	% Swell	% Hardness Change	% Swell	% Hardness Change
Buna N®	30	-3.58%	3.11%	-6.24%	13.02%
Buna N®	60	-5.61%	-6.11%	-9.32%	14.44%
Buna N®	90	-5.26%	1.56%	-8.88%	15.20%
KEL-F®	30	3.80%	N/A	N/A	N/A
KEL-F®	60	4.21%	N/A	N/A	N/A
KEL-F®	90	-0.19%	N/A	N/A	N/A
Neoprene®	30	-2.27%	-2.60%	-5.29%	9.25%
Neoprene®	60	-3.84%	4.59%	-5.62%	11.20%
Neoprene®	90	-4.86%	6.73%	-8.58%	13.53%
Silicone	30	21.88%	-9.55%	5.30%	-2.51%
Silicone	60	21.37%	-8.98%	-1.55%	-0.28%
Silicone	90	21.95%	-9.99%	-1.80%	0.73%
TFE	30	0.47%	N/A	N/A	N/A
TFE	60	1.62%	N/A	N/A	N/A
TFE	90	7.60%	N/A	N/A	N/A
VITON-A®	30	43.43%	-12.02%	17.32%	1.94%
VITON-A®	60	42.20%	-7.95%	16.98%	1.94%
VITON-A®	90	41.04%	-8.91%	14.95%	0.97%

Table 5 - HFE 7200® Compatibility					
		Post		After weight Stabilized	
O-Ring	Days	% Swell	% Hardness Change	% Swell	% Hardness Change
Buna N®	30	-5.84%	5.09%	-6.06%	8.68%
Buna N®	60	-6.35%	7.84%	-7.45%	7.65%
Buna N®	90	-6.02%	6.94%	-7.65%	10.29%
KEL-F®	30	-0.74%	N/A	N/A	N/A
KEL-F®	60	0.46%	N/A	N/A	N/A
KEL-F®	90	-0.04%	N/A	N/A	N/A
Neoprene®	30	-3.67%	4.00%	-3.97%	7.70%
Neoprene®	60	-5.27%	8.86%	-6.74%	8.09%
Neoprene®	90	2.25%	11.00%	-6.28%	11.20%
Silicone	30	20.44%	-11.21%	10.10%	-4.13%
Silicone	60	19.72%	-9.79%	-1.54%	2.35%
Silicone	90	20.32%	-5.95%	-1.81%	1.13%
TFE	30	4.45%	N/A	N/A	N/A
TFE	60	6.14%	N/A	N/A	N/A
TFE	90	6.52%	N/A	N/A	N/A
VITON-A®	30	20.96%	-9.31%	16.04%	-1.21%
VITON-A®	60	22.07%	-4.46%	14.32%	3.49%
VITON-A®	90	31.84%	-4.26%	15.34%	0.97%

Table 6 - Ikon P Compatibility					
		Post		After weight Stabilized	
O-Ring	Days	% Swell	% Hardness Change	% Swell	% Hardness Change
Buna N®	30	14.27%	-3.62%	4.26%	14.30%
Buna N®	60	11.56%	-2.15%	3.97%	19.34%
Buna N®	90	11.91%	-3.85%	1.22%	18.40%
KEL-F®	30	0.12%	N/A	N/A	N/A
KEL-F®	60	2.32%	N/A	N/A	N/A
KEL-F®	90	-0.38%	N/A	N/A	N/A
Neoprene®	30	8.67%	-6.69%	-5.39%	10.03%
Neoprene®	60	7.43%	-6.10%	1.88%	-0.86%
Neoprene®	90	10.38%	-5.13%	1.68%	0.31%
Silicone	30	114.45%	-15.25%	-1.36%	15.29%
Silicone	60	124.29%	-19.09%	-1.56%	-4.73%
Silicone	90	168.80%	-37.50%	-3.77%	-12.44%
TFE	30	9.20%	N/A	N/A	N/A
TFE	60	8.46%	N/A	N/A	N/A
TFE	90	9.63%	N/A	N/A	N/A
VITON-A®	30	19.18%	-3.88%	12.85%	3.88%
VITON-A®	60	1.96%	-2.91%	-1.46%	2.33%
VITON-A®	90	4.07%	-4.65%	12.55%	0.97%

Table 7 - Vertrel X-P10® Compatibility					
		Post		After weight Stabilized	
O-Ring	Days	% Swell	% Hardness Change	% Swell	% Hardness Change
Buna N®	30	7.61%	-3.24%	-7.13%	17.13%
Buna N®	60	8.26%	-3.85%	10.33%	16.33%
Buna N®	90	7.93%	-4.41%	-6.68%	11.24%
KEL-F®	30	-0.87%	N/A	N/A	N/A
KEL-F®	60	-2.14%	N/A	N/A	N/A
KEL-F®	90	-0.66%	N/A	N/A	N/A
Neoprene®	30	7.55%	-6.69%	-2.59%	4.39%
Neoprene®	60	2.88%	1.28%	-6.84%	11.00%
Neoprene®	90	19.97%	-4.35%	-6.64%	10.81%
Silicone	30	7.11%	-3.86%	2.16%	-0.89%
Silicone	60	11.91%	-8.85%	85.00%	-1.70%
Silicone	90	13.91%	-7.56%	5.76%	0.93%
TFE	30	6.33%	N/A	N/A	N/A
TFE	60	4.19%	N/A	N/A	N/A
TFE	90	4.88%	N/A	N/A	N/A
VITON-A®	30	69.90%	-12.40%	22.85%	2.71%
VITON-A®	60	66.61%	-5.23%	25.21%	1.98%
VITON-A®	90	63.59%	-12.21%	0.42%	2.52%

Table 8 - Vertrel XF® Compatibility					
		Post		After weight Stabilized	
O-Ring	Days	% Swell	% Hardness Change	% Swell	% Hardness Change
Buna N®	30	-1.64%	1.60%	-2.88%	11.70%
Buna N®	60	-2.49%	2.00%	-3.72%	13.50%
Buna N®	90	-3.73%	2.19%	-1.97%	15.20%
KEL-F®	30	-1.91%	N/A	N/A	N/A
KEL-F®	60	-2.01%	N/A	N/A	N/A
KEL-F®	90	-2.14%	N/A	N/A	N/A
Neoprene®	30	-0.32%	1.54%	-3.12%	10.03
Neoprene®	60	3.64%	-0.08%	-3.53%	5.95%
Neoprene®	90	-3.09%	7.70%	-5.46%	10.61%
Silicone	30	10.34%	-3.52%	-0.05%	-2.10%
Silicone	60	4.27%	-1.29%	-0.19%	0.53%
Silicone	90	4.60%	-3.52%	-0.47%	-0.08%
TFE	30	7.55%	N/A	N/A	N/A
TFE	60	7.31%	N/A	N/A	N/A
TFE	90	7.52%	N/A	N/A	N/A
VITON-A®	30	66.17%	-9.11%	20.27%	5.43%
VITON-A®	60	66.10%	-10.47%	26.40%	0.58%
VITON-A®	90	66.51%	-10.47%	30.04%	0.39%

Performance Standards for Compatibility

In order to determine which solvents would be candidates for further testing it was necessary to set up performance standards for solvents that performed well, medium performing solvents, and poorly performing solvents. The following table shows the limits for solvents that performed well (green), medium performance solvents (yellow), and poorly performing solvents (red).

Compatibility Guidelines		
Shrinkage	Swell	
>10%	> Freon 113® +30%	Red
5% - 10%	Freon 113®+15% to Freon 113® +30%	Yellow
<5% or <Freon 113®	<Freon 113® + 15%	Green

Compatibility Performance

The following tables show which performance category each solvent is in.

Compatibility with Buna N		
30 Days	60 Days	90 Days
AK 225G®	AK 225G®	AK 225G®
Freon 113®	Freon 113®	Freon 113®
HFE 7100®	HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®	HFE 7200®
Ikon P	Ikon P	Ikon P
Vertrel XF®	Vertrel XF®	Vertrel XF®
Vertrel X-P10®	Vertrel X-P10®	Vertrel X-P10®

Compatibility with Kel F		
30 Days	60 Days	90 Days
AK 225G®	AK 225G®	AK 225G®
Freon 113®	Freon 113®	Freon 113®
HFE 7100®	HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®	HFE 7200®
Ikon P	Ikon P	Ikon P
Vertrel XF®	Vertrel XF®	Vertrel XF®
Vertrel X-P10®	Vertrel X-P10®	Vertrel X-P10®

Compatibility with Neoprene		
30 Days	60 Days	90 Days
AK 225G®	AK 225G®	AK 225G®
Freon 113®	Freon 113®	Freon 113®
HFE 7100®	HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®	HFE 7200®
Ikon P	Ikon P	Ikon P
Vertrel XF®	Vertrel XF®	Vertrel XF®
Vertrel X-P10®	Vertrel X-P10®	Vertrel X-P10®

Compatibility with Silicone		
30 Days	60 Days	90 Days
AK 225G®	AK 225G®	AK 225G®
Freon 113®	Freon 113®	Freon 113®
HFE 7100®	HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®	HFE 7200®
Ikon P	Ikon P	Ikon P
Vertrel XF®	Vertrel XF®	Vertrel XF®
Vertrel X-P10®	Vertrel X-P10®	Vertrel X-P10®

Compatibility with TFE		
30 Days	60 Days	90 Days
AK 225G®	AK 225G®	AK 225G®
Freon 113®	Freon 113®	Freon 113®
HFE 7100®	HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®	HFE 7200®
Ikon P	Ikon P	Ikon P
Vertrel XF®	Vertrel XF®	Vertrel XF®
Vertrel X-P10®	Vertrel X-P10®	Vertrel X-P10®

Compatibility with Viton A		
30 Days	60 Days	90 Days
AK 225G®	AK 225G®	AK 225G®
Freon 113®	Freon 113®	Freon 113®
HFE 7100®	HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®	HFE 7200®
Ikon P	Ikon P	Ikon P
Vertrel XF®	Vertrel XF®	Vertrel XF®
Vertrel X-P10®	Vertrel X-P10®	Vertrel X-P10®

Immersion Cleaning Study Procedure

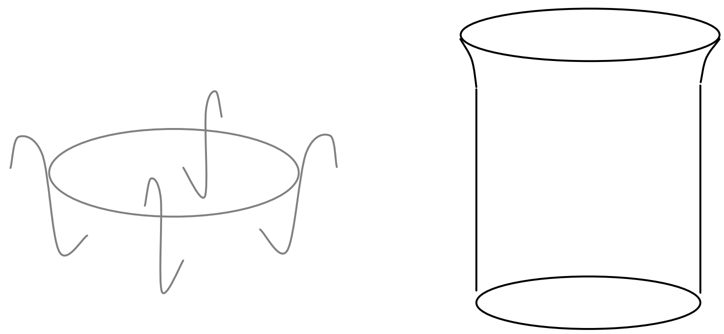
The equipment used for the cleaning study was: 2 400 mL beakers, tweezers, analytical balance, a stainless steal wire stand with 4 prongs, oven, 2" by ½" ANSI 1010 steel coupons, and an ultrasonic bath. Metal coupons were cleaned by successive washings in hexane and acetone in an ultrasonic bath prior to using them in the cleaning study and between tests. An identification number was imprinted on each coupon and they were washed again in the ultrasonic bath. After second washing, coupons were dried in an oven for 10 minutes and cooled to room temperature. Four coupons were weighed.

The contaminants for this program were based on input from the field personnel who work with the LOX and GOX systems. For oil contaminants, MIL-PRF-7808, MIL-PRF-83282, military engine oil and hydraulic fluid respectively, one drop of contaminant was placed on each coupon. The drop was spread to an area of ½ inch by ½ inch. This resulted in approximately 10mg of contaminant. Amberlube® was applied to the metal in the same manner as other liquid contaminants. Twenty milligrams of the MIL-PRF-27617, Krytox® 240AC, was spread to an area of ½ inch by ½ inch. The grease was smoothed to create uniform thickness of the contaminated area.

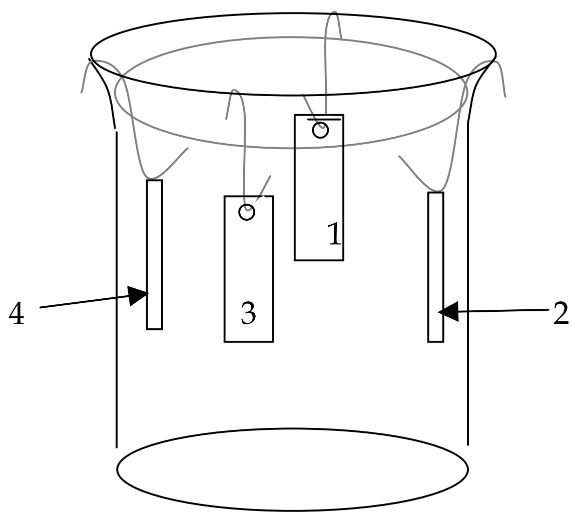
The Arizona road dust would not stick to the metal surface on its own. Ten milligrams of the Krytox® 240AC grease was spread to an area of ½ inch by ½ inch and the Arizona road dust was sprinkled onto it. The coupon was tapped so that excess dust would fall off. More dust was sprinkled and the coupon tapped until approximately 10mg of the dust stuck to the grease.

Three to five milligrams of 3M tape 250 residue was applied to the coupons. To apply the tape residue a piece of 3M tape 250 was placed onto the coupon. The coupons with the tape were placed in an oven for 24 hours at 110°C. After 24 hours the coupons were cooled to room temperature and the backing of the tape was removed. Three to five milligrams tape residue remained on the coupons.

Coupons were weighed with contaminant. The four coupons were hung on a wire stand in an empty 400 mL beaker. Another 400 mL beaker was filled with 250 mL solvent. The wire stand with the four coupons was transferred to the beaker containing solvent (see figure 2). Solvent was applied to the coupons in this manner to minimize agitation. A timer was started. After 30 seconds the first coupon was removed from solvent. The others were removed from solvent at 1, 2, and 5 minutes. The coupons were allowed to dry and then were reweighed to determine the mass of contaminant removed. The tests were conducted in duplicate. If there were inconsistencies in the data extra trials were run. Averaged data is contained in tables 9-12. Graphs of the data are in appendix 3. Where it appears that there is no data point for several solvents with the 3M tape 250, the value is 0%.



Wire Stand 400 mL beaker



1 = 30 second trial
2 = 1 minute
3 = 2 minutes
4 = 5 minutes

Figure 2

Cleaning Study Apparatus

Table 9

	Solvent, % Removed, 30 Seconds					
Solvent	MIL-PRF-83282 Hydraulic Fluid	MIL-PRF-7808 Turbine Oil	MIL-PRF-27617 Krytox® 240AC	MLO 00-398 Road Dust	Amberlube®	3M Tape No. 250
AK 225G®	98.67%	97.46%	44.43%	40.37%	17.42%	0.00%
Freon 113®	98.78%	98.32%	42.74%	57.09%	0.16%	0.00%
HFE 7100®	22.64%	22.83%	42.65%	37.30%	0.92%	10.00%
HFE 71IPA®	23.00%	78.50%	15.02%	54.07%	3.97%	2.63%
HFE 7200®	30.18%	38.31%	34.64%	33.33%	0.63%	0.00%
Ikon P	99.62%	98.02%	48.80%	58.03%	12.82%	0.00%
Vertrel XF®	53.15%	92.08%	24.04%	21.35%	2.47%	10.00%
Vertrel X-P10®	83.15%	95.06%	17.29%	45.87%	10.76%	0.00%

Table 10

	Solvent, % Removed, 60 Seconds					
Solvent	MIL-PRF-83282 Hydraulic Fluid	MIL-PRF-7808 Turbine Oil	MIL-PRF-27617 Krytox® 240AC	MLO 00-398 Road Dust	Amberlube®	3M Tape No. 250
AK 225G®	100.00%	99.58%	71.29%	48.70%	36.39%	0.00%
Freon 113®	98.66%	99.83%	74.62%	65.84%	0.00%	3.85%
HFE 7100®	34.16%	39.36%	62.97%	42.81%	0.58%	4.17%
HFE 71IPA®	58.91%	97.02%	65.32%	66.26%	2.97%	0.00%
HFE 7200®	41.09%	65.89%	54.90%	39.71%	1.97%	0.00%
Ikon P	99.49%	99.79%	44.94%	56.82%	22.22%	0.00%
Vertrel XF®	44.35%	99.22%	50.24%	39.06%	3.30%	0.00%
Vertrel X-P10®	89.79%	98.25%	21.15%	54.05%	20.53%	6.25%

Table 11

	Solvent, % Removed, 120 Seconds					
Solvent	MIL-PRF-83282 Hydraulic Fluid	MIL-PRF-7808 Turbine Oil	MIL-PRF-27617 Krytox® 240AC	MLO 00-398 Road Dust	Amberlube®	3M Tape No. 250
AK 225G®	99.62%	100.00%	85.91%	48.12%	58.76%	0.00%
Freon 113®	100.00%	100.00%	85.06%	74.28%	0.00%	11.76%
HFE 7100®	47.21%	72.83%	72.52%	43.09%	1.27%	3.85%
HFE 71IPA®	72.33%	98.42%	75.65%	54.70%	5.93%	0.00%
HFE 7200®	57.28%	91.56%	72.46%	46.85%	1.31%	0.00%
Ikon P	99.82%	98.82%	83.43%	59.92%	43.84%	0.00%
Vertrel XF®	55.29%	99.68%	63.03%	48.30%	3.29%	1.79%
Vertrel X-P10®	95.22%	98.93%	66.68%	65.46%	47.40%	6.25%

Table 12

	Solvent, % Removed, 300 Seconds					
Solvent	MIL-PRF-83282 Hydraulic Fluid	MIL-PRF-7808 Turbine Oil	MIL-PRF-27617 Krytox® 240AC	MLO 00-398 Road Dust	Amberlube®	3M Tape No. 250
AK 225G®	100.00%	99.28%	80.67%	58.44%	97.49%	3.57%
Freon 113®	98.55%	100.00%	94.95%	70.17%	0.72%	19.21%
HFE 7100®	61.48%	92.41%	77.83%	39.87%	2.01%	2.17%
HFE 71IPA®	87.98%	97.50%	79.57%	58.58%	17.66%	0.00%
HFE 7200®	78.06%	97.29%	83.56%	54.59%	1.10%	0.00%
Ikon P	99.41%	98.55%	92.26%	59.45%	82.04%	13.64%
Vertrel XF®	61.19%	98.32%	75.45%	46.23%	5.07%	0.00%
Vertrel X-P10®	96.10%	98.33%	63.62%	64.50%	92.96%	0.00%

Performance Standards for All Cleaning Studies

The cleaning standards were determined in comparison to Freon 113®. They are given in the following chart.

Cleaning Guidelines	
< 50% of Freon 113®	Red
50% to 75% of Freon 113®	Yellow
>75% of Freon 113®	Green

Static Immersion Cleaning Performance

The following tables show the cleaning performance of each solvent for each contaminant by immersion only. There is no table for 3M tape 250 because none of the solvents, including Freon 113®, cleaned the tape residue consistently.

Cleaning of Krytox® 240AC			
.5 min	1min	2min	5min
AK 225G®	AK 225G	AK 225G	AK 225G®
Freon 113®	Freon 113®	Freon 113®	Freon 113®
HFE 7100®	HFE 7100®	HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®	HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®	HFE 7200®	HFE 7200®
Ikon P	Ikon P	Ikon P	Ikon P
XF®	XF®	XF®	XF®
X-P10®	X-P10®	X-P10®	X-P10®

Cleaning of Krytox/Arizona Rd Dust			
.5 min	1min	2min	5min
AK 225G®	AK 225G®	AK 225G®	AK 225G®
Freon 113®	Freon 113®	Freon 113®	Freon 113®
HFE 7100®	HFE 7100®	HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®	HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®	HFE 7200®	HFE 7200®
Ikon P	Ikon P	Ikon P	Ikon P
XF®	XF®	XF®	XF®
X-P10®	X-P10®	X-P10®	X-P10®

Cleaning of MIL-PRF-7808			
.5 min	1min	2min	5min
AK 225G®	AK 225G®	AK 225G®	AK 225G®
Freon 113®	Freon 113®	Freon 113®	Freon 113®
HFE 7100®	HFE 7100®	HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®	HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®	HFE 7200®	HFE 7200®
Ikon P	Ikon P	Ikon P	Ikon P
XF®	XF®	XF®	XF®
X-P10®	X-P10®	X-P10®	X-P10®

Cleaning of MIL-PRF-83282			
.5 min	1min	2min	5min
AK 225G®	AK 225G®	AK 225G®	AK 225G®
Freon 113®	Freon 113®	Freon 113®	Freon 113®
HFE 7100®	HFE 7100®	HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®	HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®	HFE 7200®	HFE 7200®
Ikon P	Ikon P	Ikon P	Ikon P
XF®	XF®	XF®	XF®
X-P10®	X-P10®	X-P10®	X-P10®

Cleaning of Amberlube®

0.5 min	1 min	2 min	5 min
AK 225G®	AK 225G®	AK 225G®	AK 225G®
Freon 113®	Freon 113®	Freon 113®	Freon 113®
HFE 7100®	HFE 7100®	HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®	HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®	HFE 7200®	HFE 7200®
Ikon P	Ikon P	Ikon P	Ikon P
XF®	XF®	XF®	XF®
X-P10®	X-P10®	X-P10®	X-P10®

Wipe Cleaning Investigation

Since one of the primary cleaning methods to be used with the solvent was a wipe solvent, it was important to determine the extent to which the mechanical action of wiping increased the cleaning efficiency of the solvents. To minimize the variability associated with different pressures and speeds of the wiper by hand, a Gardner Scrubbability apparatus was used.

Wipe Cleaning Study Procedure

[3]Equipment used for the wipe cleaning study was: Modified Gardner Washability Test Apparatus, analytical balance, oven, NSN-7920-00-634-2408/Machinery Wiping Towels (see figure 3), aluminum panels, and steel panels. Tests were run in duplicate. These tests were run at the Phoenix Chemical Laboratory, Inc in Chicago IL. Two drops of a liquid contaminant or an equivalent volume of a grease were placed on a clean weighed panel. The contaminant was spread to an area of 1.5 by 3 inches, insuring liquid soil weights of approximately 20±3 mg and grease weights 32±3 mg. The panels were weighed. The panels with a liquid contaminant were dried at 100°C for 15 minutes before weighing.

Application Road Dust to Aluminum Panels:

Approximately 200 mg of Arizona road dust was spread over the surface of a panel. The panel was tilted and the dust tapped off. A ¼ inch edge of the panel was wiped clean to leave an area of 1.5 by 3.5 inches. The remnant layer of dust was misted with deionized water and dried for 30 minutes at 100°C. This resulted in approximately 2±1 mg contaminant.

Application of Road Dust to Steel Panels:

Panels were sprinkled with small amount of dust. Application of road dust was finished in the same way as the aluminum panels.

A 1 by 3-inch piece of 3M Tape 250 was centered on a clean weighed panel. Panels with tape were aged at 100°C for 48 hours. Panels were cooled to room temperature. Tape backing was removed.

Each panel was placed in the Gardner Scrubability Machine (see Figure 3). Approximately 20 mL of solvent was applied to saturate the wiper. The panels were subjected to 1 double stroke of the scrubber at a weight of 1 lb. After cleaning, metals were dried at 100^{o}C for 15 minutes, cooled, and weighed.

The averaged data is contained in table 13. Graphs of the data are in Appendix 4.

Calculations for All Cleaning Studies

$$\%Removal = \frac{WeightSoiledPanelBeforeCleaning - WeightSoiledPanelAfterCleaning}{WeightSoiledPanelBeforeCleaning - WeightUnsoiledPanel}$$

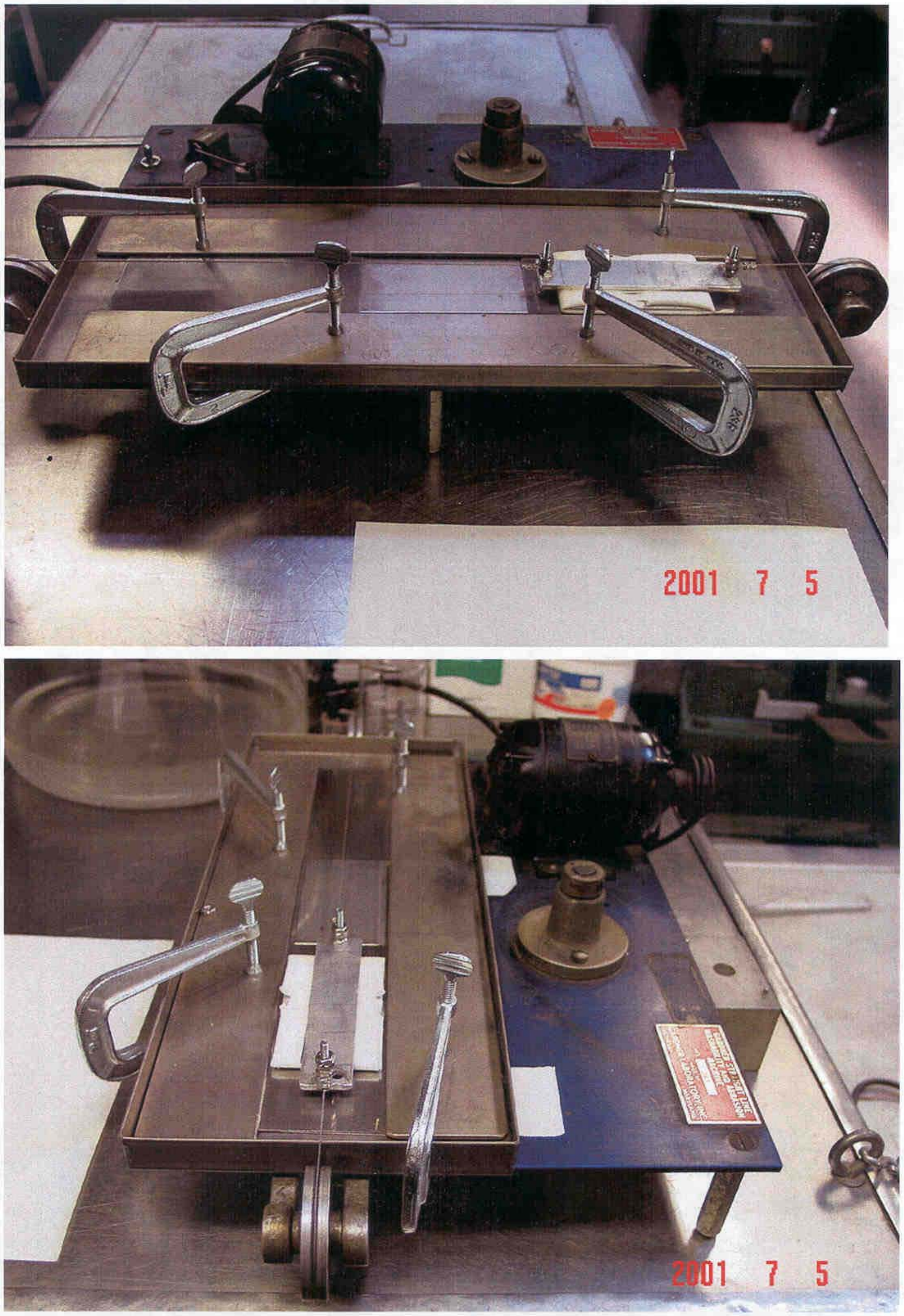


Figure 3-Gardner Scrubability Apparatus

Table 13

Steel / Aluminum	SOIL, % Removed				
SOLVENT	MIL-PRF-83282 Hydraulic Fluid	MIL-PRF-7808 Turbine Oil	MIL-PRF-27617 Krytox®	MLO 00-398 Road Dust	3M Tape 250
MLO 00-375 Ikon P	90.4 / 89.5	90.9 / 89.8	85.6 / 88.6	94.8 / 92.7	50.0 / 58.3
MLO 00-185 AK 225G®	93.9 / 92.9	90.6 / 91.0	90.6 / 90.4	99.1 / 100	10.0 / 33.3
MLO 00-367 HFE 7100®	83.4 / 87.5	90.9 / 96.0	89.5 / 90.3	92.0 / 93.7	25.0 / 50.0
MLO 00-368 HFE-71 IPA®	84.6 / 83.3	92.9 / 90.8	87.9 / 90.6	88.0 / 96.2	35.0 / 50.0
MLO 00-369 HFE 7200®	89.2 / 86.7	90.1 / 91.8	90.7 / 92.7	93.3 / 96.9	83.3 / 54.2
MLO 00-370 X-P10 Vertrel®	95.0 / 92.6	92.0 / 96.0	89.3 / 93.9	95.3 / 100	50.0 / 75.0
MLO 00-371 XF Vertrel®	87.4 / 88.1	90.7 / 89.7	91.2 / 91.2	88.1 / 100	41.7 / 75.0
Freon 113 TF®	88.2 / 90.6	92.7 / 90.1	88.6 / 82.2	84.8 / 86.6	50.0 / 58.3

Wipe Cleaning Performance

The following tables show the wipe cleaning performance of each solvent for each contaminant.

Cleaning of Krytox® 240AC	
Steel	Aluminum
AK 225G®	AK 225G®
Freon 113®	Freon 113®
HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®
Ikon P	Ikon P
XF®	XF®
X-P10®	X-P10®

Cleaning of Arizona Rd Dust	
Steel	Aluminum
AK 225G®	AK 225G®
Freon 113®	Freon 113®
HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®
Ikon P	Ikon P
XF®	XF®
X-P10®	X-P10®

Cleaning of MIL-PRF-7808	
Steel	Aluminum
AK 225G®	AK 225G®
Freon 113®	Freon 113®
HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®
Ikon P	Ikon P
XF®	XF®
X-P10®	X-P10®

Cleaning of MIL-PRF-83282	
Steel	Aluminum
AK 225G®	AK 225G®
Freon 113®	Freon 113®
HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®
Ikon P	Ikon P
XF®	XF®
X-P10®	X-P10®

Cleaning of 3M Tape 250	
Steel	Aluminum
AK 225G®	AK 225G®
Freon 113®	Freon 113®
HFE 7100®	HFE 7100®
HFE 71IPA®	HFE 71IPA®
HFE 7200®	HFE 7200®
Ikon P	Ikon P
XF®	XF®
X-P10®	X-P10®

Interim Conclusions

At this point in the program a meeting was held. The wiper action increased the cleaning efficiency of all the solvents significantly. In fact a wiper with no solvent cleaned 50% of all soils, so some modification of the test conditions was in order. Some conclusions regarding cleaning ability could be drawn from the static immersion cleaning studies to enable at least two solvents to progress to the next level of testing. It was decided that Ikon P and AK 225G® were the best candidates to replace Freon 113®. One more solvent was desired for continued testing. HFE 7100®, Vertrel XF®, and Vertrel X-P10® were the next three best candidates but were indistinguishable in their wipe cleaning ability. A modified wipe cleaning test was decided upon to pick one of these solvents to continue in further testing. (At this point the results of the NASA White Sands Test Facility was not complete. If that data had been available the Vertrel X-P10 would not have been continued based on the flammability tests.)

Modification 1 of the Wipe Cleaning Procedure

[3]The procedure was modified to use a scrubber weight of 66.5 g. The contaminant was applied at thicknesses of 50, 100, and 150 mg/ft^2. The rest of the procedure

remained the same. HFE 7100, Vertrel X-P10, and Vertrel XF were retested with the modified procedure for MIL-PRF-7808 as the contaminant.

Modification 1 Results

Solvent	Average % Removed	Contaminant Loading (mg/ft^2)
HFE 7100®	94.4	50
Vertrel X-P10®	86.3	50
Vertrel XF®	91.7	50
None	28	50
HFE 7100®	94.6	100
Vertrel X-P10®	75.1	100
Vertrel XF®	94.3	100
None	18.6	100
HFE 7100®	84.8	150
Vertrel X-P10®	92.6	150
Vertrel XF®	87.1	150
None	16.4	150

Modification 2 of the Wipe Cleaning Procedure

[3]The procedure was modified again to use a scrubber weight of 66.5 g but this time a single stroke rather than a double stroke. The single stroke procedure was investigated because during the double stroke trials, it appeared that some of the contaminant that had been removed during the forward stroke was redeposited on the coupon during the backward stroke.

Modification 2 Results

Wipe Cleaning ability of Solvents with MIL-PRF-7808

Solvent Name	Average % Removed	Contaminant Loading (mg/ft^2)
AK 225G®	66.7	50
HFE 7100®	38.6	50
Vertrel XF®	82.1	50
Vertrel X-P10®	91.8	50
None	7.0	50
AK 225G®	93.8	100
HFE 7100®	37.4	100
Vertrel XF®	86.1	100
Vertrel X-P10®	87.7	100
AK 225G®	91.4	150
HFE 7100®	49.8	150
Vertrel XF®	86.4	150
Vertrel X-P10®	86.6	150
None	8.3	150

Wipe Cleaning ability of Solvents with Krytox® 240AC

Solvent Name	Average % Removed	Contaminant Loading (mg/ft^2)
AK 225G®	60.4	50
HFE 7100®	64.9	50
Vertrel XF®	73.3	50
Vertrel X-P10®	58.9	50
AK 225G®	35.3	100
HFE 7100®	72.7	100
Vertrel XF®	82.7	100
Vertrel X-P10®	52.2	100
AK 225G®	33	150
HFE 7100®	67.6	150
Vertrel XF®	86	150
Vertrel X-P10®	70.9	150

This procedure did provide more differentiation in the cleaning abilities of these solvents.

Manual Wipe Cleaning Procedure

[4]Additional manual wipe testing was done on Freon 113®, HFE 7100®, HFE 7200®, and Vertrel XF®. These tests were conducted at NASA White Sands Test Facility. Coupons measuring 2 by 4 inches were cleaned and weighed. A contaminating solution of 1 mg contaminant per 1 mL Freon 113® was prepared. One milliliter of the contaminating solution was dripped onto the coupon and allowed to volatilize. Coupons were reweighed. This method applied 0.4 mg to 1 mg contaminant to the coupon. A 4 by 4 inch square of lint free, clean room wiper was loaded with 2 mL solvent. Each edge of the wiper was held between the thumb and index finger of one hand. The center of the wiper was moved across the coupon. The coupon was allowed to dry for 5 minutes and then reweighed. The final weight was taken after 30 minutes.

For low temperature tests the contaminated coupon and the solvent were placed in a refrigerator at 5°C for 2 hours prior to running the procedure listed above. For the high temperature test the contaminated coupon was placed in an oven at 50°C for 2 hours prior to running the cleaning procedure.

The contaminants used were Krytox®240AC and Amberlube®.

Manual Wipe Data/Results

Cleaning Ability of Solvents for Krytox® 240AC			
Solvent	Low Temp	Room Temp	High Temp
HFE 7100®	54%±5%	73%±4%	59%±4%
HFE 7200®	49%±4%	59%±2%	33%±4%
Vertrel XF®	52%±5%	62%±3%	48%±7%
None	-	33%±3%	-
Freon 113®	59%±3%	66%±4%	59%±4%

Cleaning Ability of Solvents for Amberlube	
Solvent	Room Temp
HFE 7100®	53%±4%
HFE 7200®	43%±6%
Vertrel XF®	56%±5%
Freon 113®	98%±2%

Field Evaluation Cleaning Study

All field evaluations were performed at Edwards Air Force Base, CA. At the conclusion of the AIT, LOX compatibility, Static Cleaning, Wipe Cleaning, and Seal Compatibility tests, 5 solvents were chosen for field evaluations. They were Ikon P, AK 225G®, Vertrel XF®, HFE 7100®, and HFE 7200®. In this work HFE 7200 replaced Vertrel X-P10 because of Vertrel X-P10 failing performance in the NASA White Sands Test Facility evaluation. Phase 1 evaluated the cleaning ability of each solvent. Phase 2 determined the amount of each solvent necessary to insure cleanliness of an oxygen line. Phase 3 tested cleanliness by visual inspection.

Phase 1 Field Evaluation Procedure

[5]Solutions of 0, 1, 6, 12, and 150 ppm contaminant in Freon 113® were prepared. The contaminants used were MIL-PRF-5606 hydraulic fluid, MIL-PRF-83282 hydraulic fluid, MIL-PRF-7808 engine oil, and MIL-PRF-2050 tube bending oil. A Fourier transform infrared spectroscopy analysis was run on each sample to determine absorbance.

Four parts were cleaned with Freon 113®. The parts used were a wrench, a T-fitting, an AN cap, and a 6 inch metal flex line. Parts were contaminated with a known amount of hydrocarbon contaminant. The cap, T-fitting, and line were immersed in solvent and sonicated for 1 minute. The wrench was wiped with a cotton wipe that had been folded in quarters and soaked in 2.5 mL solvent. After cleaning, the part was dried in a vacuum oven for 5 minutes. Parts were immersed in Freon 113® and sonicated for 5 minutes, except the line, which was sonicated for 7 minutes.

The Freon 113® was collected and analyzed by Fourier transform infrared (FTIR) spectroscopy to determine how much contaminant had not been removed by the candidate replacement solvent.

Phase 1 Results/Data

Cleaning Ability of Solvents for Varying Parts and Contaminants					
Part/Contaminant	AK 225G®	Ikon P	HFE 7200®	HFE 7100®	Vertrel XF®
Cap/MIL-PRF-5606	99.4%	99.0%	73.8%	61.0%	83.0%
T-Fitting/MIL-PRF-7808	99.8%	99.7%	99.5%	99.5%	-
Line/MIL-PRF-83282	98.8%	-	74.4%	53.2%	31.5%
Wrench/MIL-PRF-83282	89.7%	99.1%	98.6%	98.3%	-

Phase 2 Procedure

[5]A 13.35 inch x ¼ inch ID metal line was cleaned with Freon 113®. The Freon 113® was then analyzed by FTIR to insure cleanliness prior to start of test. The line was weighed. The line was contaminated with 10 mg of 2050 tube bending oil or MIL-PRF-83282 hydraulic fluid. A measured amount of solvent was poured into line that has one end capped. The other end then was capped. The line was swished with a rocking motion. The line was drained and another aliquot of solvent was poured in and swished. The line was drained and dried with nitrogen for 30 seconds. Four milliliters of Freon 113® was placed in the line and was swished 50 times. The Freon 113® rinse was analyzed by FTIR to determine how much contaminant was left in the line after cleaning with other solvents. The total maximum allowable contaminant was calculated to be 0.11 mg.

Phase 2 Results Data

Contaminant	Contaminant Wt (g)	Solvent	Solvent Volume (mL)	# of Washes	# of Swishes	Contaminant Wt (mg) Remaining	Pass or Fail
2050	0.0074	Freon 113®	4	2	25	0.02	Pass
2050	0.0111	Freon 113®	3	2	25	0.02	Pass
2050	0.0093	Freon 113®	2	2	25	0.05	Pass
2050	0.0106	Freon 113®	1	2	25	0.2	Fail
2050	0.0110	Freon 113®	3	2	10	0.09	Pass
2050	0.0110	Freon 113®	2	2	10	0.51	Fail
83282	0.0082	Freon 113®	4	2	25	0.02	Pass
2050	0.0080	AK 225G®	4	2	25	0.04	Pass
2050	0.0088	AK 225G®	1	2	25	0.4	Fail
2050	0.0098	AK 225G®	2	2	25	0.17	Fail
2050	0.0092	AK 225G®	3	2	25	0.06	Pass
2050	0.0090	AK 225G®	1	1	25	1.11	Fail
2050	0.0104	AK 225G®	2	1	25	0.51	Fail
2050	0.0096	AK 225G®	3	1	25	0.42	Fail
2050	0.0094	AK 225G®	4	1	25	0.25	Fail
83282	0.0076	Vertrel XF®	4	2	25	3.33	Fail
2050	0.0074	Vertrel XF®	4	2	25	Saturated	Fail
83282	0.0067	HFE 7100®	4	2	25	3.35	Fail
2050	0.0214	HFE 7100®	4	2	25	5.24	Fail
2050	0.0097	HFE 7100®	4	2	25	4.69	Fail
2050	0.0090	HFE 7100®	5	3	25	4.27	Fail
2050	0.0105	HFE 7100®	5	10	25	6.08	Fail
83282	0.0092	Ikon P	4	2	25	<0.01	Pass
2050	0.0181	Ikon P	4	2	25	0.04	Pass
83282	0.0080	HFE 7200®	4	2	25	0.12	Fail
2050	0.0087	HFE 7200®	4	2	25	Saturated	Fail
2050	0.0219	HFE 7200®	4	2	25	Saturated	Fail

Phase 3 Procedure

[5]A coating of MIL-PRF-83282 was applied to the exterior of an oxygen fill valve nozzle using a saturated cotton swab. Dirt was applied to the nozzle by holding it over the dirt while nitrogen was blown over the dirt. The nozzle was sprayed with a solvent using a new Type A spray bottle for each test until the part appeared clean.

Phase 3 Data/Results

Solvent	Volume (mL)	Visual Cleanliness
AK 225G®	~50	Yes
Ikon P	~50	Yes
Vertrel XF®	Excessive	No
HFE 7100®	Excessive	No
HFE 7200®	Excessive	No
Freon 113®	~50	Yes

Conclusions

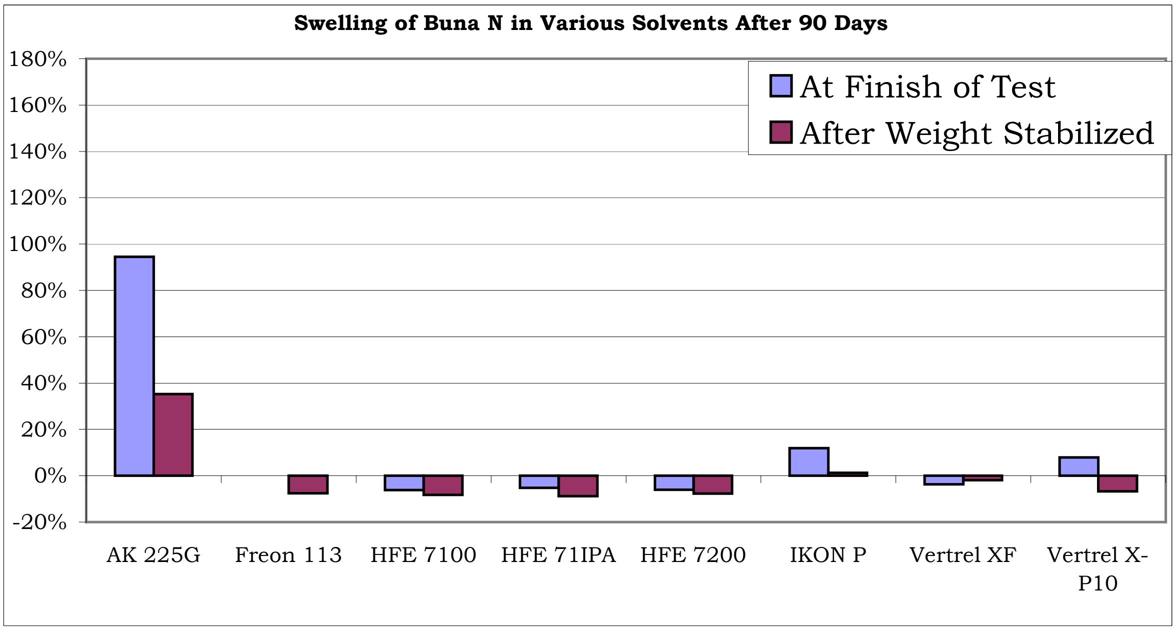
HFE 71IPA® and Vertrel X-P10® were determined to be unsuitable for further testing. The following is a table of the red, yellow, or green performance of the solvents that passed. It also includes the Liquid Oxygen Compatibility (LOX), Auto Ignition Temperature (AIT), and toxicity performances attained from outside experiments.

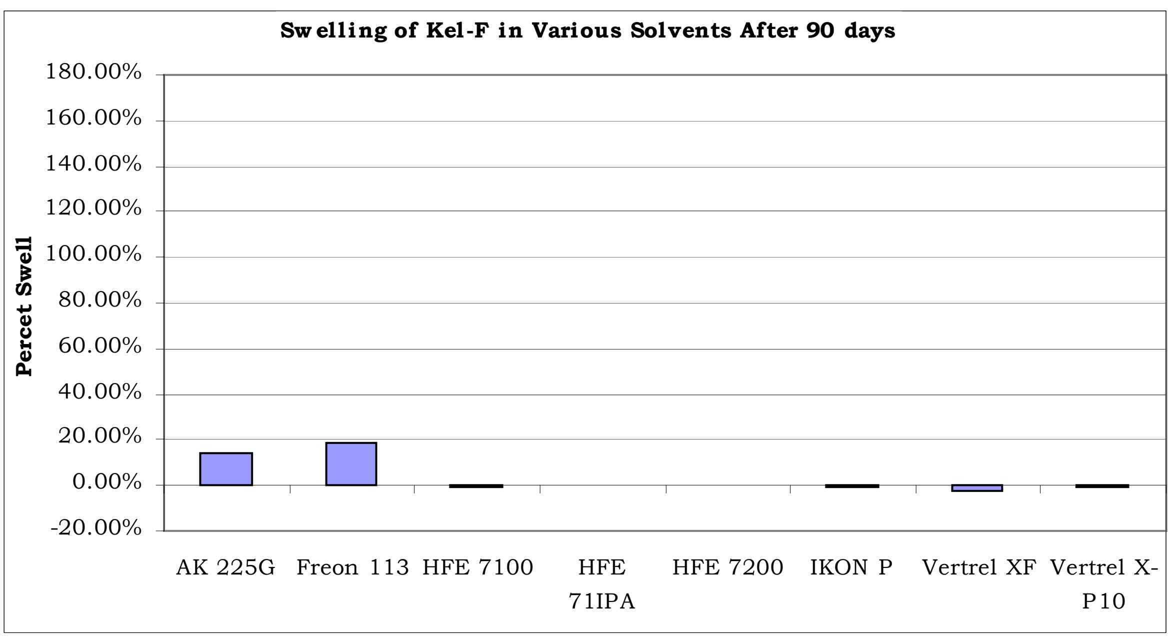
LOX	AIT	Solvency Cleaning	Wipe Cleaning	Compatibility	Toxicity
AK 225G®	AK 225G®	AK 225G®	AK 225G®	AK 225G®	AK 225G®
HFE 7100®	HFE 7100®	HFE 7100®	HFE 7100®	HFE 7100®	HFE 7100®
HFE 7200®	HFE 7200®	HFE 7200®	HFE 7200®	HFE 7200®	HFE 7200®
Ikon P	Ikon P	Ikon P	Ikon P	Ikon P	Ikon P
Vertrel XF®	Vertrel XF®	Vertrel XF®	Vertrel XF®	Vertrel XF®	Vertrel XF®

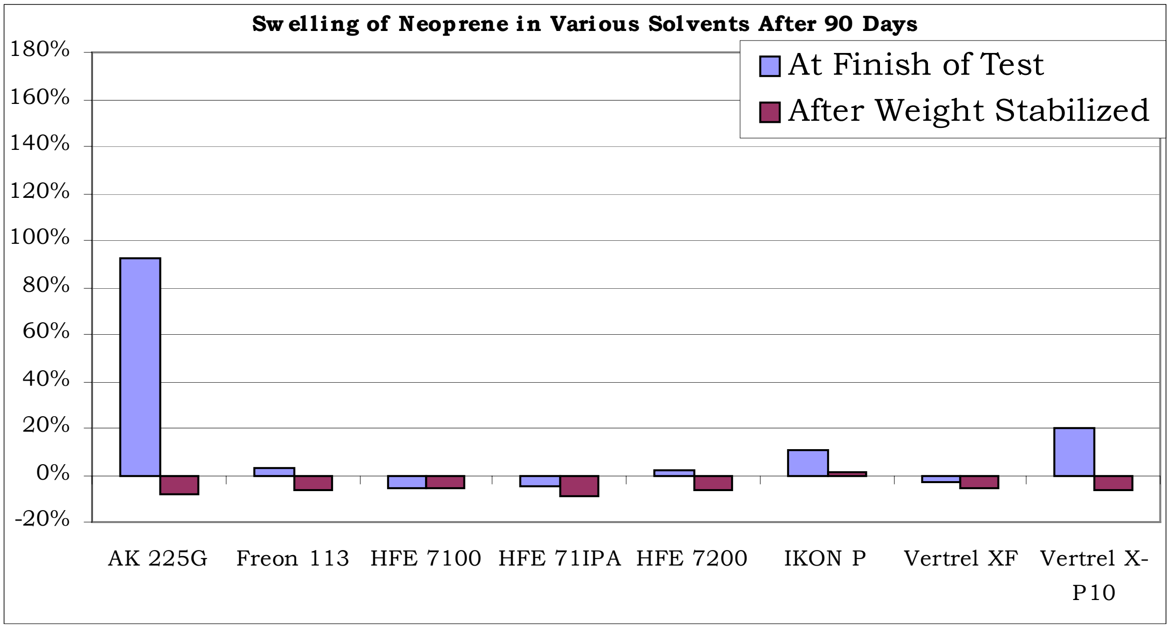
From the above table, it can be seen that no single solvent is clearly superior in all respects although the Ikon P was the only candidate replacement solvent determined not to be unacceptable in any respect.

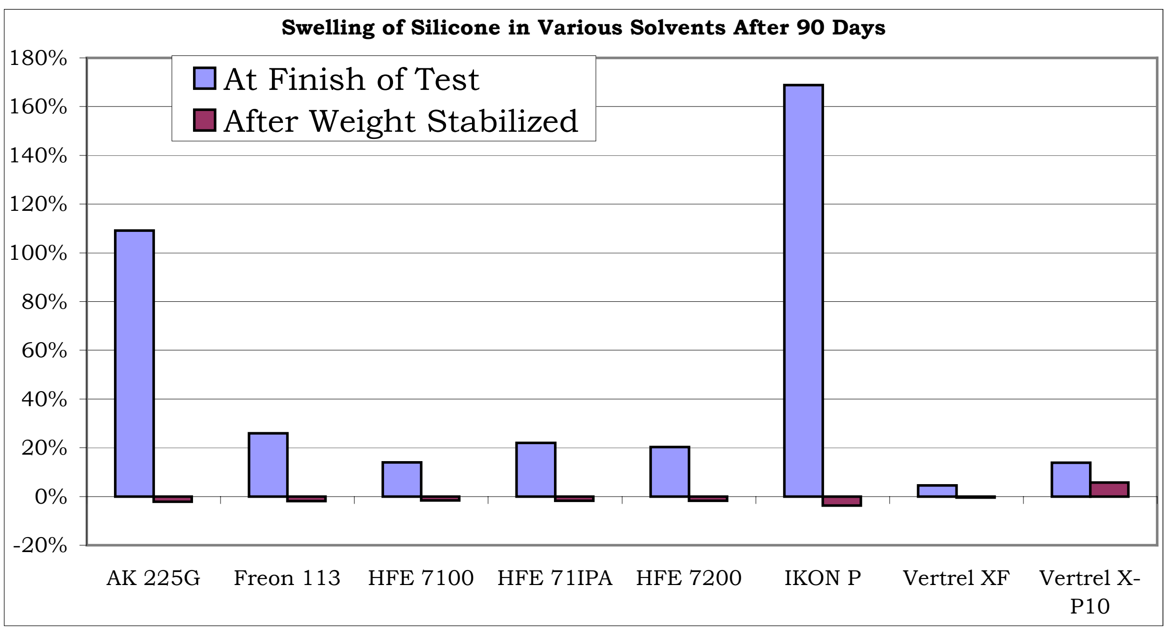
Appendix 1: Compatibility Data Graphs—Swelling

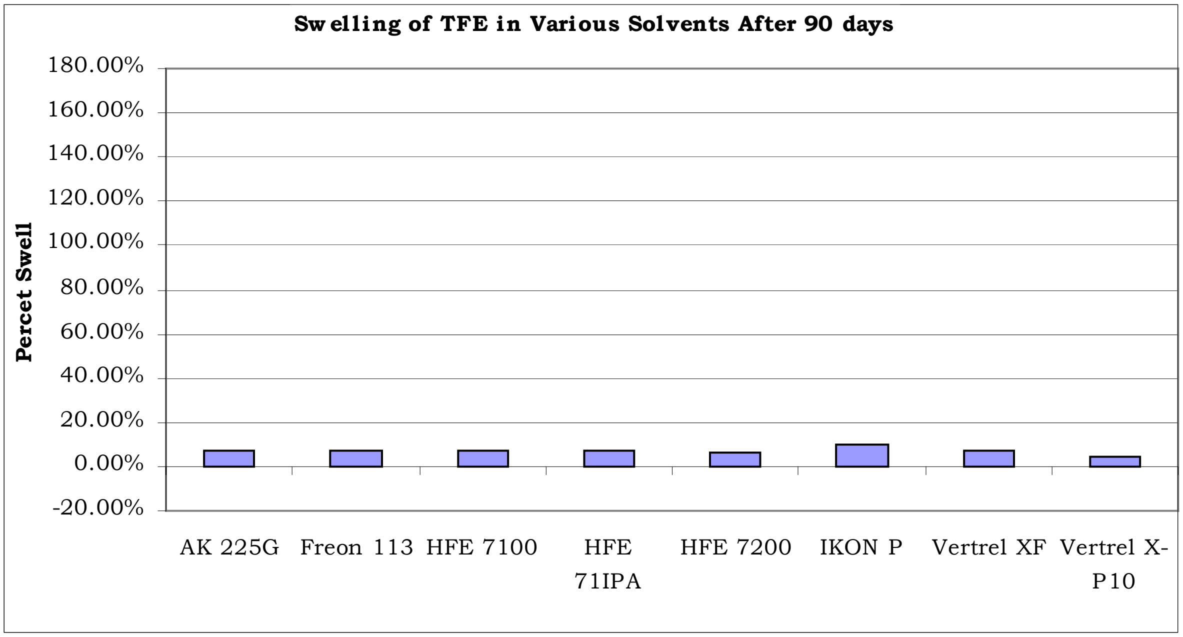
*For all graphs, if there appears to be no bar the value is Zero.
*For the swell and hardness change graphs, Kel F and TFE were only measured immediately at the end of the test. They are hard materials and did not need "after weight stabilized" measurements, as did the softer materials.

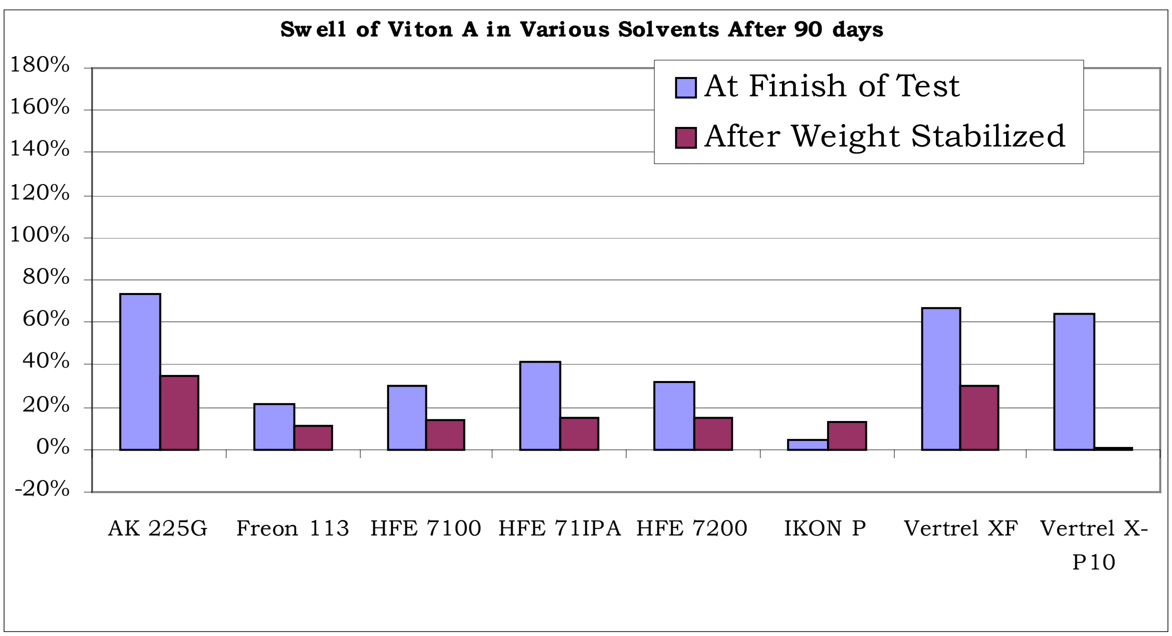




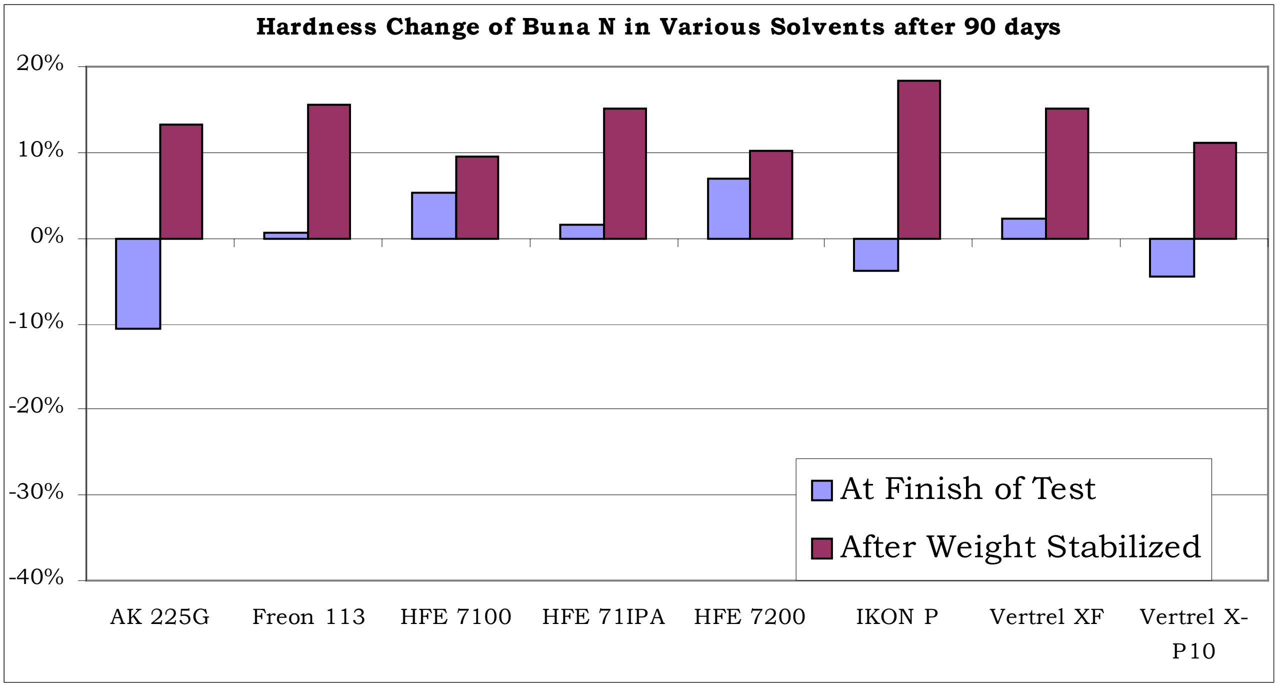

Swelling of Neoprene in Various Solvents After 90 Days
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
-20%
At Finish of Test
After Weight Stabilized
AK 225G
Freon 113
HFE 7100
HFE 71IPA
HFE 7200
IKON P
Vertrel XF
Vertrel X-P10

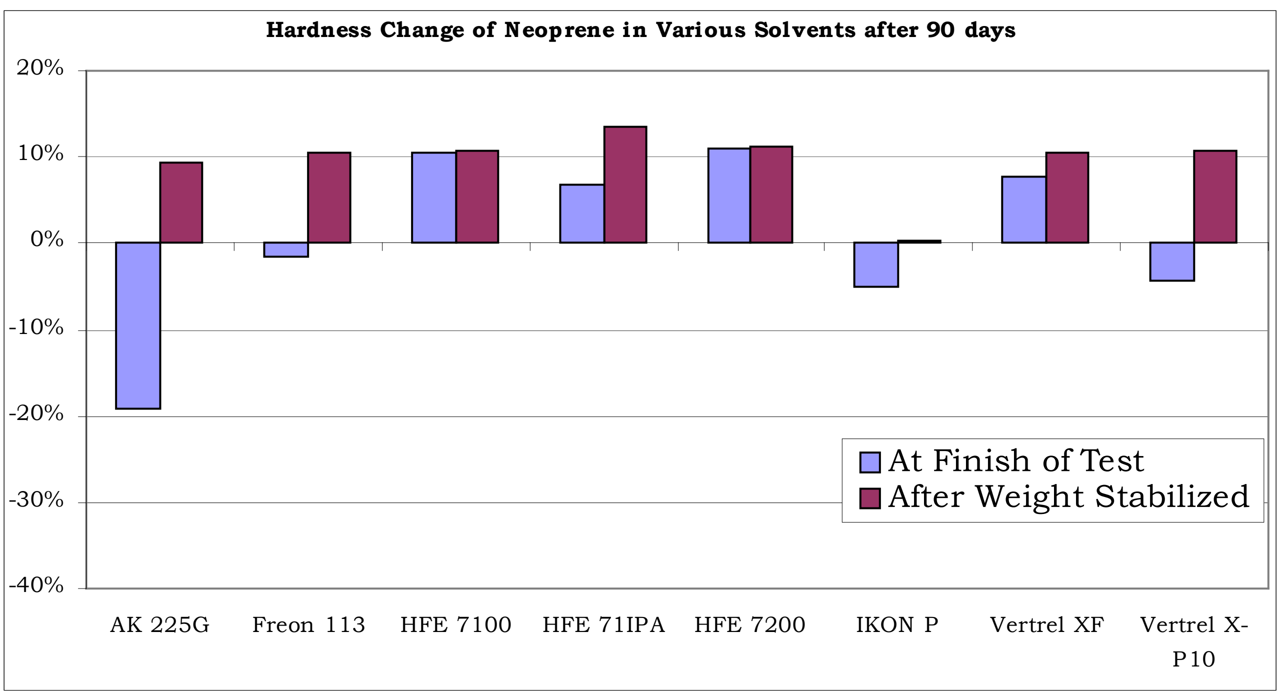

Swelling of Silicone in Various Solvents After 90 Days
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
-20%
At Finish of Test
After Weight Stabilized
AK 225G
Freon 113
HFE 7100
HFE 71IPA
HFE 7200
IKON P
Vertrel XF
Vertrel X-P10

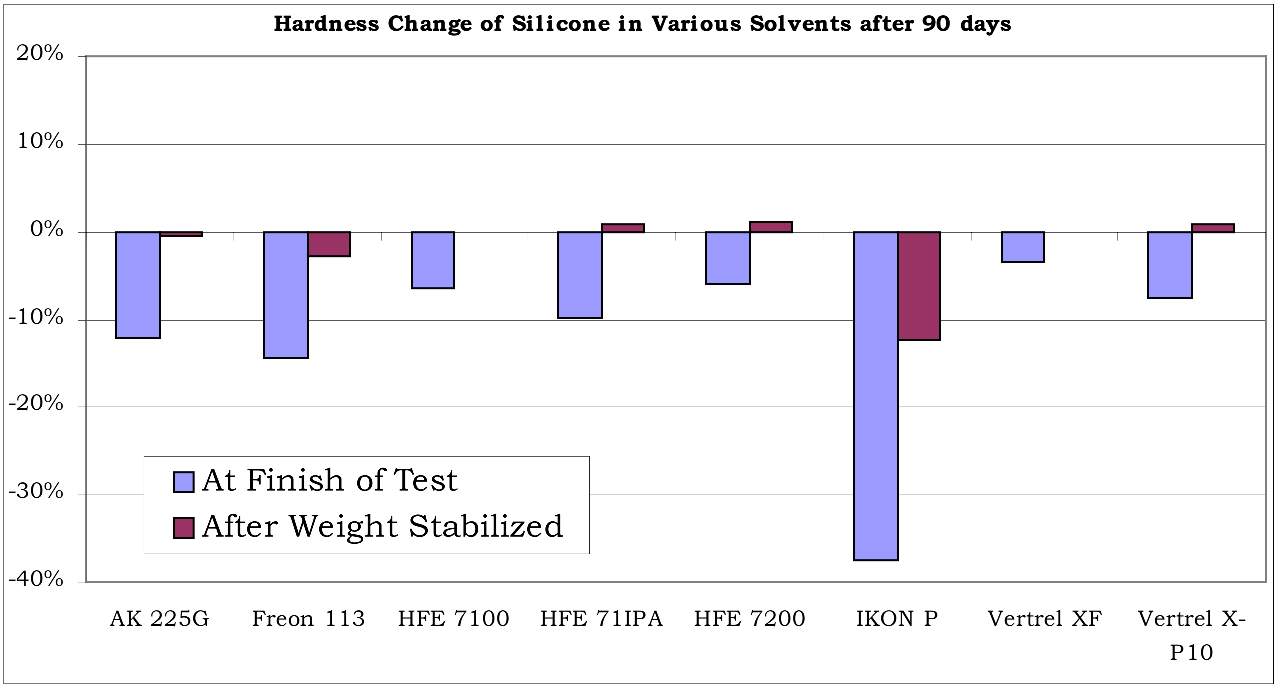

Swelling of TFE in Various Solvents After 90 days
Percet Swell
180.00%
160.00%
140.00%
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
-20.00%
AK 225G
Freon 113
HFE 7100
HFE 71IPA
HFE 7200
IKON P
Vertrel XF
Vertrel X-P10


Swell of Viton A in Various Solvents After 90 days
At Finish of Test
After Weight Stabilized
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
-20%
AK 225G
Freon 113
HFE 7100
HFE 71IPA
HFE 7200
IKON P
Vertrel XF
Vertrel X-P10

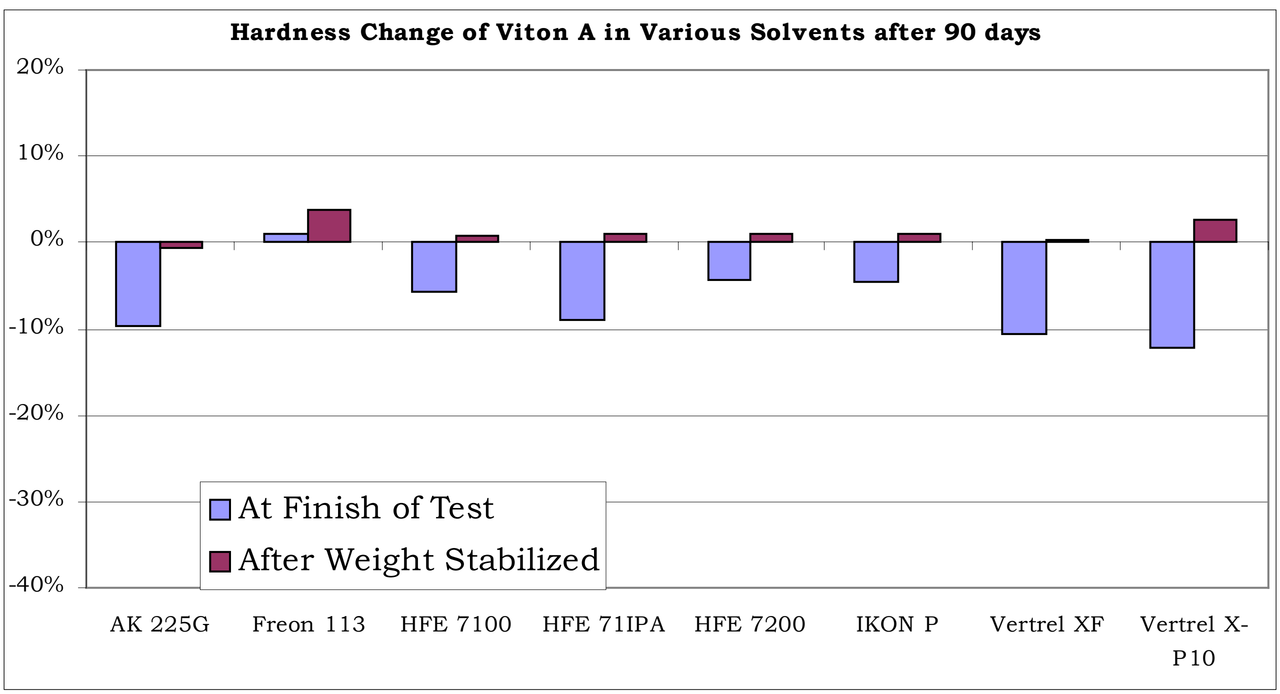
Appendix 2: Compatibility Data Graphs—Hardness Change





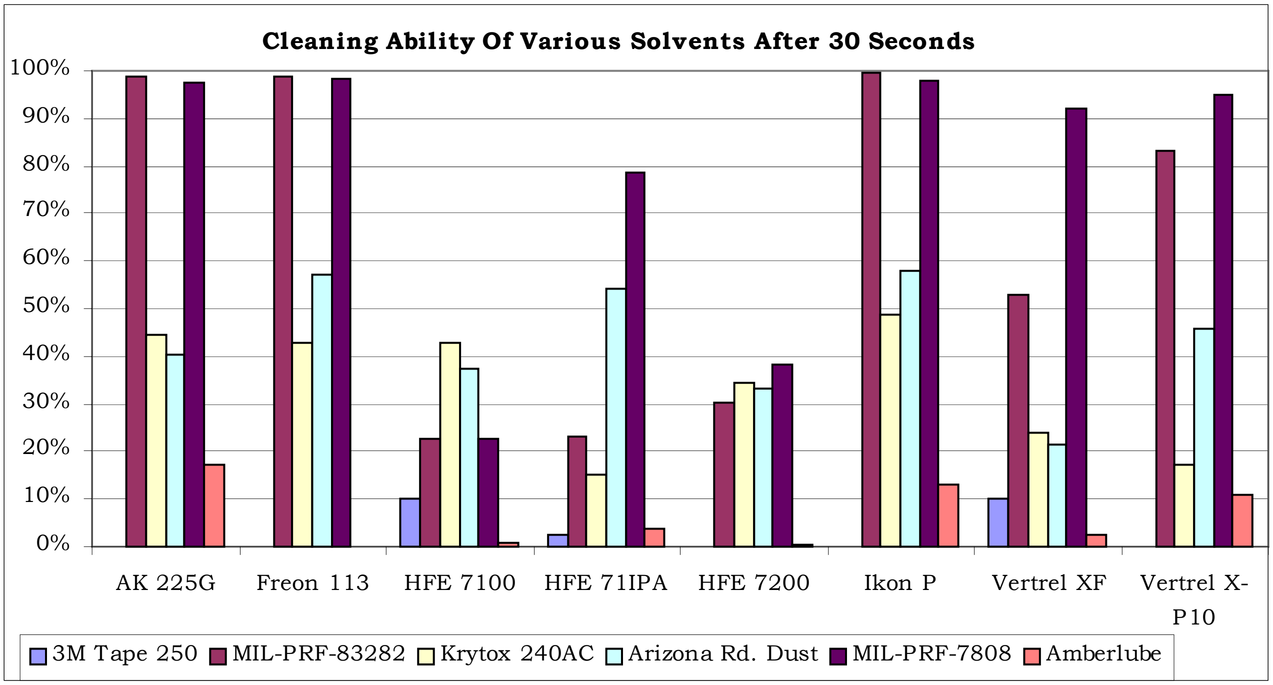


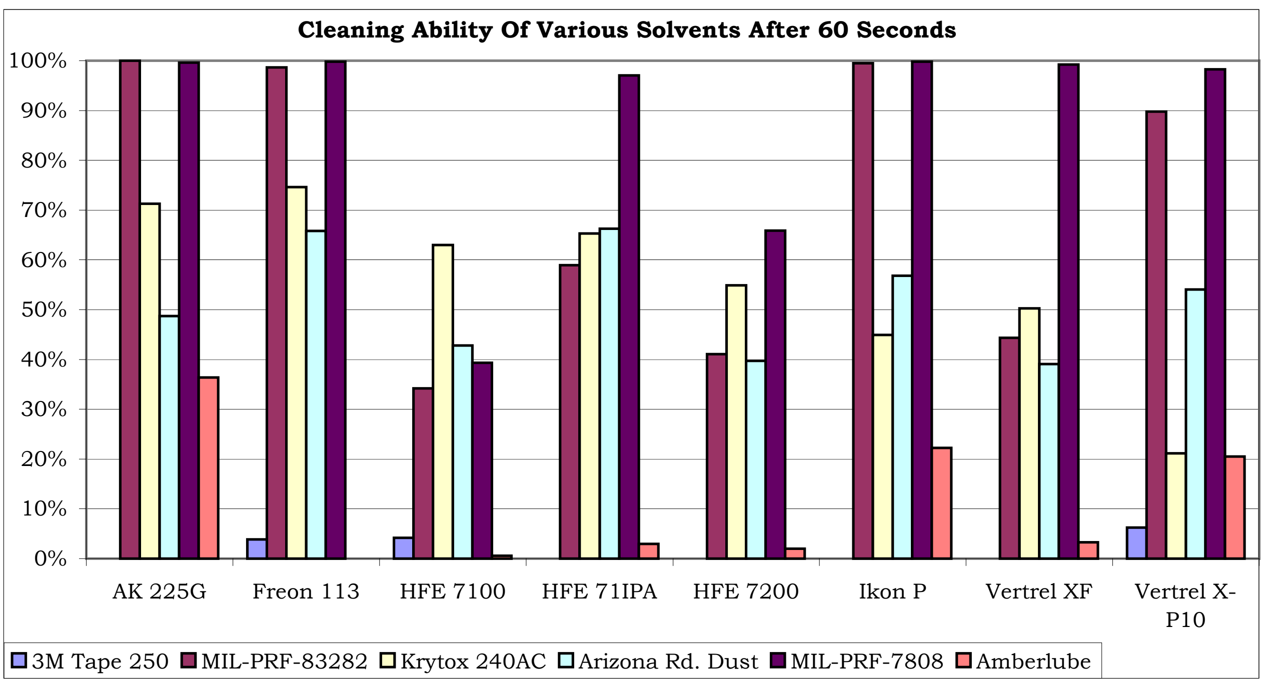
Hardness Change of Silicone in Various Solvents after 90 days
20%
10%
0%
-10%
-20%
-30%
-40%
At Finish of Test
After Weight Stabilized
AK 225G
Freon 113
HFE 7100
HFE 71IPA
HFE 7200
IKON P
Vertrel XF
Vertrel X-P10

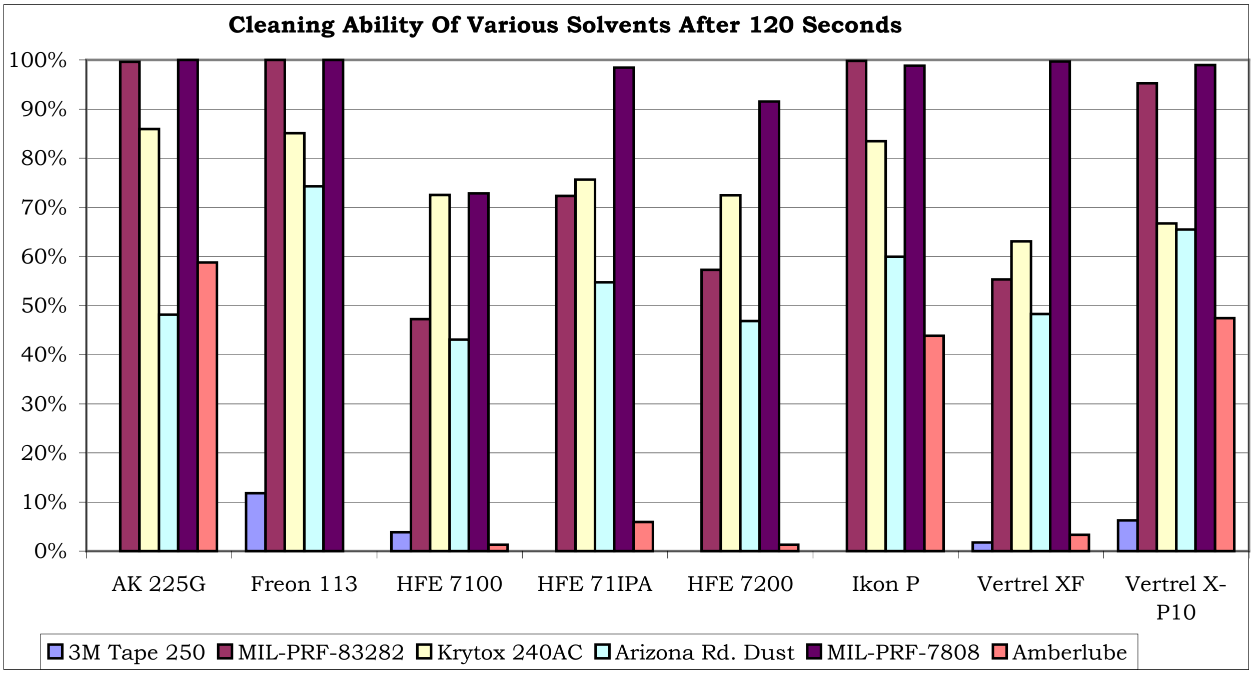


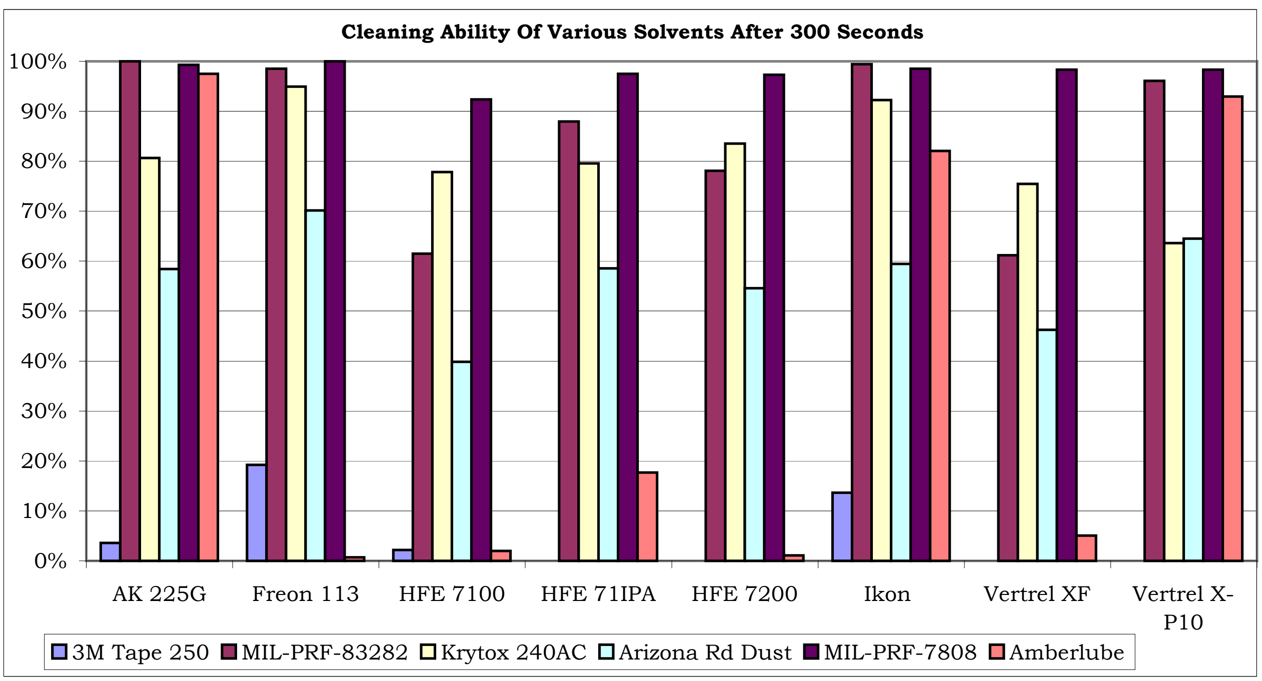
Hardness Change of Viton A in Various Solvents after 90 days
20%
10%
0%
-10%
-20%
-30%
-40%
At Finish of Test
After Weight Stabilized
AK 225G
Freon 113
HFE 7100
HFE 71IPA
HFE 7200
IKON P
Vertrel XF
Vertrel X-P10

Appendix 3: Immersion Cleaning Data Graphs

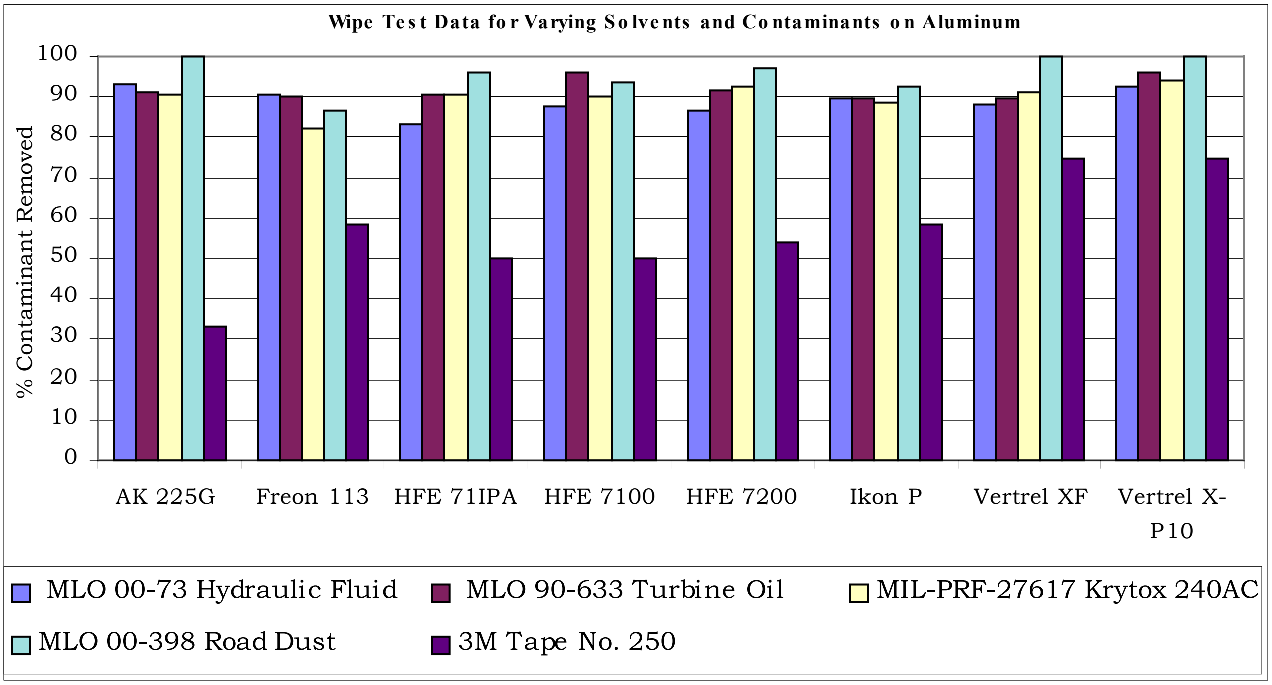


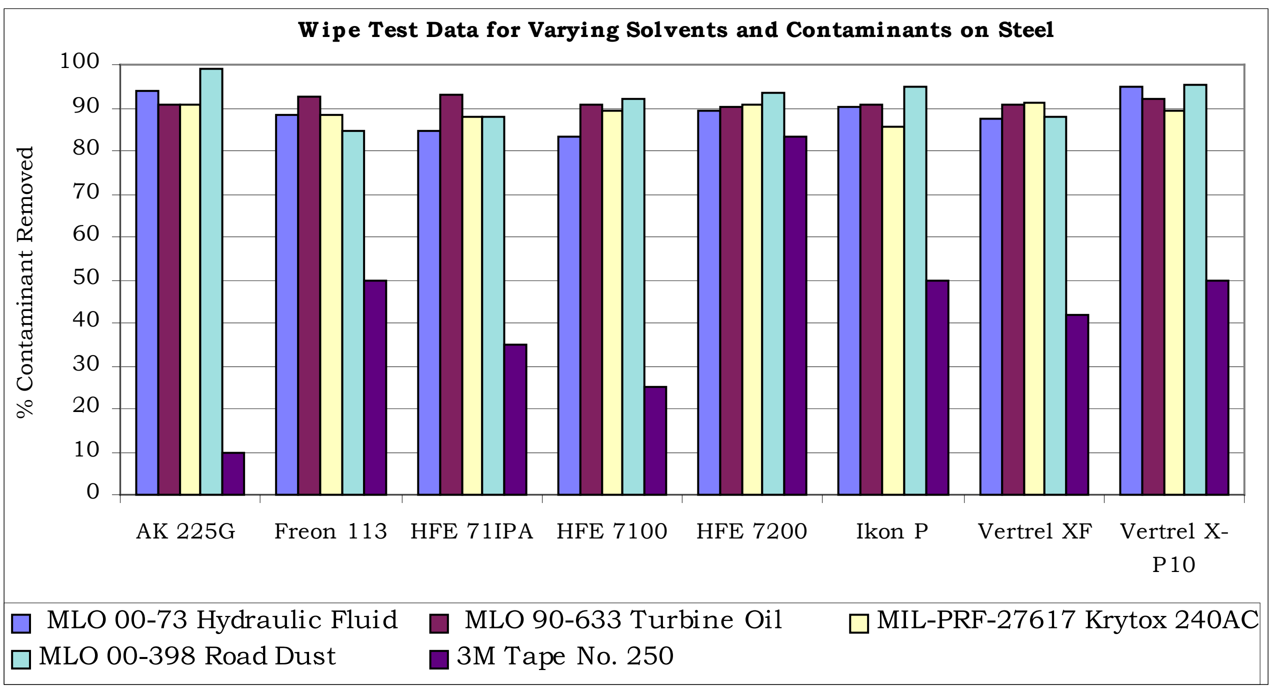



Cleaning Ability Of Various Solvents After 120 Seconds
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
AK 225G
Freon 113
HFE 7100
HFE 71IPA
HFE 7200
Ikon P
Vertrel XF
Vertrel X-P10
3M Tape 250
MIL-PRF-83282
Krytox 240AC
Arizona Rd. Dust
MIL-PRF-7808
Amberlube


Cleaning Ability Of Various Solvents After 300 Seconds
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
AK 225G
Freon 113
HFE 7100
HFE 71IPA
HFE 7200
Ikon
Vertrel XF
Vertrel X-P10
3M Tape 250
MIL-PRF-83282
Krytox 240AC
Arizona Rd Dust
MIL-PRF-7808
Amberlube

Appendix 4: Wipe Cleaning Data Graphs





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